

10/558154

MAP20 Rec'd PCT/PTO 23 NOV 2005

DESCRIPTION

CERAMIC COMPOSITION

Technical Field

5 The present invention relates to ceramic compositions. In particular, it relates to a ceramic composition usable as, for example, a material for a multilayer substrate used for propagation of signals in a high-frequency band.

10 Background Art

Recent years saw development in high-speed, large-capacity data communications and cellular communications. With respect to multilayer substrates having integrated circuits, this development led to not only size-reduction 15 and increased density but also investigations as to use of signals having frequencies in a high-frequency band ranging from, for example, several ten megahertz to several hundred gigahertz. While ceramic compositions are used in these multilayer substrates, it is desirable that the ceramic 20 compositions be made of a material (high-frequency band material) compatible with signals in the high-frequency band.

Typically, alumina (Al_2O_3) has been primarily used as the ceramic composition for the high-frequency band. As the density of the integrated circuits increases, there has been 25 developed a process of making a multilayer substrate

including an integrated circuit, the process including
stacking a plurality of green sheets composed of unsintered
 Al_2O_3 , each green sheet having a conductor paste that
contains a material for metal wiring applied by printing,
5 and then simultaneously baking the green sheets and the
conductor paste. Since Al_2O_3 sinters at a temperature as
high as $1,500^\circ\text{C}$ to $1,600^\circ\text{C}$, a high melting point-metal, such
as tungsten or molybdenum, which can withstand such a high
temperature, has been required as the material for the metal
10 wiring of the integrated circuit.

The multilayer substrate has a problem in that it
requires a large amount of energy since the sintering
temperature is high, thereby increasing the manufacturing
cost. Since the thermal expansion coefficient of Al_2O_3 is
15 larger than that of the IC chip, such as a silicon chip, in
the integrated circuit, the multilayer substrate may suffer
from cracks depending on the operating temperature of the
multilayer substrate. Furthermore, since the relative
dielectric constant of Al_2O_3 is large, the rate of signal
20 propagation in the integrated circuit has been low. Since
the specific resistance of a high melting point-metal, such
as tungsten or molybdenum, is large compared to that of Cu
or Ag, which is suitable as a material for the metal wiring,
the conductor loss due to the resistance of the metal wiring
25 itself has also been large.

In view of the above, various ceramic compositions each
in which a filler is incorporated in a glass composition
have been developed as the material for multilayer
substrates. Multilayer substrates using such ceramic
5 compositions can be sintered at a temperature lower than
that when Al_2O_3 is used. Thus, it becomes possible to
simultaneously sinter the ceramic compositions and the
material for metal wiring, such as Cu or Ag, having a
smaller specific resistance. Furthermore, since the filler
10 is contained in the glass composition, the change in shape
of the ceramic composition can be reduced, and the strength
of the ceramic composition can be increased.

For example, Japanese Examined Patent Application
Publication No. 3-53269 described an example of such a
15 ceramic composition, prepared by sintering a mixture of a
 $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-B}_2\text{O}_3$ glass composition and 50 to 35 mass% of
 Al_2O_3 as a filler at 800°C to 1,000°C. Japanese Patent No.
3277169 discloses a ceramic composition containing 0 to 10
mol% of Al_2O_3 as a filler and a glass composition including
20 50 to 67 mol% of B_2O_3 , 2 to 3 mol% of an oxide of an alkali
metal element, 20 to 50 mol% of an oxide of an alkaline
earth metal element, and 2 to 15 mol% of an oxide of a rare
earth element. Japanese Unexamined Patent Application
Publication No. 9-315855 discloses a ceramic composition
25 containing an oxide of a rare earth element, Al_2O_3 , CaO , and

TiO₂, and in which the compounding ratio of these components is limited within a particular range.

The performances required for the ceramic composition for the high-frequency band include a low dielectric loss 5 tanδ in the high-frequency band and a small absolute value of the temperature coefficient τ_f of the resonant frequency.

In other words, the loss in the course of signal propagation in the high-frequency band is preferably as small as possible. Thus, it is desirable that the 10 dielectric loss tanδ of the ceramic composition in the high-frequency band be small, i.e., that the Q value (1/tanδ) be large. Moreover, in order to yield stable performance from the ceramic composition serving as a dielectric member despite a temperature change, it is desirable that the 15 absolute value of the temperature coefficient τ_f of the resonant frequency be small, i.e., that the temperature dependence of the resonant frequency be low.

Disclosure of Invention

20 Under the above-described circumstances, an object of the present invention is to provide a ceramic composition that can be sintered at a low temperature and has a small dielectric loss in the high-frequency band and a low temperature dependence of the resonant frequency.

An aspect of the present invention provides a ceramic composition including a glass composition and a filler incorporated in the glass composition, the filler including at least one of Al_2O_3 and TiO_2 , wherein the composition of
5 the ceramic composition includes 0.15 to 0.55 mol of **a**, 0.45 to 0.85 mol of **b**, 0.01 to 0.2 mol of an oxide RO of an alkaline earth metal element R, and 0.1 to 0.4 mol of the
filler, wherein **a** represents a molar quantity of an oxide Ln_2O_3 of a rare earth element Ln, **b** represents a molar
10 quantity of boron oxide B_2O_3 , and **a + b = 1 mol.**

Preferably, the ceramic composition includes 0.05 mol or less of tungsten oxide WO_3 , wherein **a** represents a molar quantity of an oxide Ln_2O_3 of a rare earth element Ln, **b** represents a molar quantity of boron oxide B_2O_3 , and **a + b = 1 mol.**

Preferably, the ceramic composition includes 0.0005 to 0.002 mol of an oxide M_2O of an alkali metal element M, wherein **a** represents a molar quantity of an oxide Ln_2O_3 of a rare earth element Ln, **b** represents a molar quantity of
20 boron oxide B_2O_3 , and **a + b = 1 mol.**

Best Mode for Carrying Out the Invention

The present inventor has conducted various studies on the composition in order to obtain a ceramic composition
25 that can be sintered at a low temperature and has a small

dielectric loss in the high-frequency band and a low temperature dependence of the resonant frequency.

It has been found that a ceramic composition in which a filler composed of an inorganic oxide is incorporated in a 5 glass composition is most suitable as such a ceramic composition. The internal structure of the ceramic composition is a network structure composed of a glass composition filling the gaps between the respective particles of the filler. Since the material usable as the 10 filler is limited within a certain range, the characteristics of the glass composition must be improved to further improve the performance.

Thus, the material for the glass composition was studied first. In particular, the sintering temperature of 15 the glass composition, the compatibility with the filler, the relative dielectric constant, the dielectric loss in the high-frequency band, and the temperature dependence of the resonant frequency were investigated. Of these items, the dielectric characteristic was measured by a dielectric 20 resonator method (short-circuited at both ends of a dielectric resonator), i.e., Hakki & Coleman method, using a cylindrical test sample after sintering.

In general, the dielectric loss is evaluated in terms of Q value, which is obtained by the sharpness of the 25 resonance. The Q value is frequency-dependent and decreases

in proportion to the frequency. In contrast, the resonant frequency changes with the shape and the dielectric constant of the test sample. Thus, the dielectric loss of the ceramic composition is evaluated by comparative assessment
5 in terms of the product fQ of the resonant frequency fo and Q.

As a result of the studies on various glass compositions, it has been found that a glass composition containing a large amount of crystals obtained by mixing an
10 oxide Ln_2O_3 of a rare earth element (also referred to as "Ln") and boron oxide B_2O_3 exhibits a particularly low dielectric loss. In this glass composition, crystals of LnBO_3 , LnB_3O_6 , Ln_3BO_3 , or $\text{Ln}_4\text{B}_2\text{O}_9$ appear depending on the compounding ratio, and the phase of these crystals
15 presumably decreases the dielectric loss.

However, in order to adjust the composition of the glass composition composed of only two components, i.e., Ln_2O_3 and B_2O_3 , to yield a low dielectric loss, the melting temperature must be increased, and thus, the sintering
20 temperature required for obtaining a dense sinter becomes high. It was found that by adding an adequate amount of an oxide RO of an alkaline earth metal element R (wherein R represents at least one of Mg, Ca, Sr and Ba) to the composition composed of Ln_2O_3 and B_2O_3 , the sintering
25 temperature can be decreased without significantly affecting

the dielectric loss.

Here, the target performance of the ceramic composition is set as follows: that the value fQ (f_0 [GHz] $\times Q$) at around 10 GHz is 15,000 or higher; that the change in resonant frequency with temperature is small; and that the composition can be sintered at a temperature as low as $1,000^{\circ}\text{C}$ or less, which is the temperature at which metal wiring composed of a highly conductive material, Ag or Cu, can be simultaneously formed to produce a multilayer substrate. The investigations on the composition of the ceramic composition were carried out based these. That the change in resonant frequency with temperature be small is important for the stable operation of the integrated circuit. The resonant frequency was measured while varying the temperature, and the rate of change in resonant frequency (temperature characteristic τ_f) with the varying temperature was evaluated. The target range of the temperature characteristic τ_f of the resonant frequency was set to within $\pm 50 \text{ ppm}/^{\circ}\text{C}$ ($-50 \text{ ppm}/^{\circ}\text{C} \leq \tau_f \leq +50 \text{ ppm}/^{\circ}\text{C}$).
It was also found that incorporation of tungsten oxide, WO_3 , was effective for decreasing the sintering temperature. It was found that when an excessively large amount of WO_3 was incorporated, the change in resonant frequency with temperature tended to shift toward the negative side.
It was found that incorporation of a small amount of an

oxide M_2O of an alkali metal element M (wherein M represents at least one selected from Li, Na, and K) can further decrease the sintering temperature. In particular, incorporation of M_2O can effectively decrease the sintering 5 temperature when a process of mixing all the starting materials and then sintering the resulting mixture in one step to obtain a ceramic composition is employed.

The filler is important for maintaining the strength of the ceramic composition and the shape during the sintering. 10 Here, one or both of Al_2O_3 and TiO_2 are used as the filler. When the strength is desired, Al_2O_3 is primarily used whereas TiO_2 is primarily used when a large dielectric constant is desired. However, when the amount of filler is excessively large, the sintering temperature must be increased. When 15 the amount of the filler is excessively small, the strength and the shape can no longer be maintained. Thus, the amount of the filler is limited by these factors.

The present invention has been made based on these results of studies by specifically setting the limit of the 20 composition range of the ceramic composition. The ceramic composition of the present invention includes a glass composition and a filler contained in the glass composition and is sintered at a low temperature. The reasons for limiting the amount of each component of the composition are 25 as follows.

Where the content of the oxide Ln_2O_3 of the rare earth element Ln in the ceramic composition of the present invention is represented by **a**, the content of the boron oxide B_2O_3 in the ceramic composition of the present invention is represented by **b**, and $\mathbf{a} + \mathbf{b} = 1 \text{ mol}$, **a** is 0.15 to 0.55 mol and **b** is 0.45 to 0.85 mol.

These content ranges are necessary for decreasing the dielectric loss in the high-frequency band and for performing low-temperature sintering. When the contents of Ln_2O_3 and B_2O_3 are set as above, excellent dielectric characteristic, i.e., a high fQ value, can be yielded by the generation of crystals represented by $\text{Ln}_x\text{B}_y\text{O}_z$ (wherein x , y , and z each represent an integer). In other words, where $\mathbf{a} + \mathbf{b} = 1 \text{ mol}$ and **a** is less than 0.15 and **b** is more than 0.85, B_2O_3 that cannot form $\text{Ln}_x\text{B}_y\text{O}_z$ enters a liquid phase, thereby increasing the glass phase. Thus, the dielectric loss cannot be decreased. Where $\mathbf{a} + \mathbf{b} = 1 \text{ mol}$ and **a** is more than 0.55 and **b** is less than 0.45, the sintering temperature increases, and a ceramic composition composed of a dense sinter cannot be obtained by the target low-temperature sintering.

Note that any of the rare earth elements represented by Ln can increase the fQ value. Thus, in this invention, one or more rare earth elements can be selected. In particular, when La and/or Nd is used as the rare earth element, an fQ

value higher than that achieved by other rare earth elements can be obtained. However, the sintering temperature and the dielectric constant of the ceramic composition differ depending on the type of rare earth element. Thus, these properties may be adequately adjusted by changing the type of the rare earth element or by changing the content of the oxide RO of the alkaline earth metal element R described below.

The content of the each component described below is indicated in terms of a molar ratio with respect to one mole of the total of Ln_2O_3 and B_2O_3 .

The content of the oxide RO of the alkaline earth metal element R is 0.01 to 0.2 mol. At an RO content less than 0.01 mol, the sintering temperature cannot be decreased. At an RO content exceeding 0.2 mol, the temperature characteristic τ_f of the resonant frequency becomes lower than -50 ppm/ $^{\circ}\text{C}$, i.e., excessively shifted toward the negative side, thereby increasing the temperature dependence.

At least one of MgO , CaO , SrO , and BaO may be used as the oxide RO of the alkaline earth metal R. In particular, the fQ value tends to be larger with CaO compared to that with oxides of other alkaline earth metals.

Preferably, tungsten oxide WO_3 is contained in the ceramic composition of the present invention. When WO_3 is contained, a dense sinter can be obtained by low-temperature

sintering, which is the target of the present invention, while increasing the fQ value. In order to achieve such an effect, WO_3 is preferably contained in an amount of 0.05 mol or less and more preferably in an amount of 0.005 to 0.05 mol. At a WO_3 content exceeding 0.05 mol, the fQ value decreases, and the temperature characteristic τ_f of the resonant frequency tends to significantly shift toward the negative side. When the WO_3 content is less than 0.005 mol, the above-described effect is not easily achieved. In the present invention, WO_3 is not an essential component.

The ceramic composition of the present invention preferably contains 0.0005 to 0.002 mol of an oxide M_2O of an alkali metal element M. In this manner, the sintering temperature can be further decreased. In general, a glass composition containing alkali metal ions exhibits a large dielectric loss and a small fQ value due to ionic induction. At an M_2O content of 0.002 mol or less, the fQ value is rarely affected. At an M_2O content of 0.0005 mol or more, the sintering temperature tends to decrease.

One or both of Al_2O_3 and TiO_2 in a total amount of 0.1 to 0.4 mol per mole of the total of Ln_2O_3 and B_2O_3 are contained as the filler. At a filler content less than 0.1 mol, excessive deformation may occur during sintering and the strength of the ceramic composition after the sintering may become insufficient. At a filler content exceeding 0.4

mol, the sintering temperature is increased, and it may be difficult to conduct low-temperature sintering at 1,000°C or less. In order to increase the strength of the ceramic composition, Al₂O₃ may be singularly used or the content of 5 Al₂O₃ may be increased. In order to increase the dielectric constant of the ceramic composition, TiO₂ may be singularly used or the content of TiO₂ may be increased.

There are mainly two methods as the method for producing the ceramic composition of the present invention.

10 According to a first method, powders of starting materials for ceramic composition are prepared, and the powders are respectively weighed to yield a desired composition. The powders are wet-mixed in a ball mill, dried, and calcined at about 800°C. The resulting calcined material is pulverized 15 to obtain a powder. A binder is added to the powder, and the resulting mixture is kneaded and formed into a desired shape to obtain a compact. The compact is heated to remove the binder and sintered to obtain the ceramic composition of the present invention.

20 According to a second method, powders of starting materials for the glass composition are prepared and respectively weighed to yield a desired composition. The powders are mixed with each other, and the resulting mixture is melted by heating at 1,000°C or higher and rapidly cooled 25 to produce a glass frit. The glass frit is pulverized. The

filler was separately sintered and pulverized to prepare a powder. The glass frit, the filler, and the binder are mixed and kneaded, and formed into a compact. The binder is removed from the compact, and the resulting compact is
5 sintered to prepare a ceramic composition of the present invention. In this second method, with respect to the glass frit containing Al_2O_3 and/or TiO_2 serving as the filler, it is possible to mix and knead the filler and the binder.

The above-described compact can be sintered at a
10 temperature as low as 800°C to 1,000°C. At a sintering temperature less than 800°C, the sintering of the ceramic composition may not be insufficient, and density is not satisfactory. Thus, satisfactory strength may not be exhibited. When the ceramic composition of the present
15 invention is used as a material for a multilayer substrate and is sintered simultaneously with the material for metal wiring, the material for the metal wiring may be heated to a temperature higher than the melting point and may start to melt. However, at a temperature or 1,000°C or less, the
20 sintering can be performed without melting the material for the metal wiring, such as Cu or Ag. It should be noted that when Cu is used as the material for metal wiring, a reducing atmosphere is preferable to avoid possible oxidation, and when Ag is used as the material for metal wiring, the
25 sintering temperature is preferably up to 930°C.

The above-described materials for the ceramic composition are not necessarily oxides as long as they are contained in the ceramic composition by forming oxides after the sintering. Thus, for example, carbonate salts, such as 5 CaCO_3 , and compounds, such as nitrides, e.g., BN, other than oxides may be used as the starting materials. Although these starting materials may contain impurities, they can be treated as single compounds as long as the impurity content is 5 mass% or less with respect to the mass of the 10 respective compound and the same effects can be still be achieved.

In making a multilayer substrate having an integrated circuit by using the ceramic composition of the present invention, the material after kneading is first formed into 15 sheets to prepare green sheets, and a conductive paste containing the material for metal wiring is applied on each green sheet by printing. A plurality of green sheets with the conductive paste applied thereon is stacked and sintered.

Here, a constraint sintering process in which the 20 compact obtained by stacking a plurality of green sheets having the conductive paste applied thereon by printing is sintered while applying pressure or constraint in the vertical direction may be employed. According to this process, the contraction due to sintering is limited in the 25 vertical direction, i.e., the Z direction, and no

contraction occurs in the surface direction, i.e., the X-Y direction. A multilayer substrate having superior surface flatness can be accurately obtained as a result.

Preferably, green sheets composed of Al_2O_3 or the like
5 that do not sinter at the sintering temperature of the ceramic composition are provided on the upper and lower surfaces, respectively, of the compact, and the compact is preferably sintered while applying pressure or constraint through these green sheets. Here, it is important that the
10 Al_2O_3 green sheets on the upper and lower surfaces of the compact be easily separable and that the metal wiring after the sintering sufficiently adhere onto the ceramic composition so as to avoid conduction failure. Studies were conducted whether this process can be applied to the ceramic
15 composition. The results confirmed that this process can be applied without any problem.

(EXAMPLES)

The starting material powders of the respective components were adequately weighed to give ceramic
20 compositions having compositions shown in Tables 1 to 5. The starting material powders were all oxides. Deionized water was added to the starting material powders, and the resulting mixture was wet-mixed for 20 hours in a ball mill containing zirconia balls.

25 The resulting mixture was dried and calcined at 700°C

for 2 hours. The calcined mixture was pulverized to obtain a calcined powder. The calcined powder was combined with 10 mass% of a PVA aqueous solution serving as a binder, and the resulting mixture was kneaded, granulated, and press-formed 5 into a compact having a diameter of 15 mm and a height of 7.5 mm. However, Samples 60, 61, and 62 shown in Table 3 were prepared by melting the materials excluding the filler by heating to 1,300°C, rapidly cooling the resulting materials to form a glass frit, adding a predetermined 10 amount of the filler to the glass frit, adding 10 mass% of a PVA aqueous solution serving as a binder to the resulting mixture, kneading and granulating the resulting mixture, and press-forming the resulting mixture into a compact having a diameter of 15 mm and a height of 7.5 mm.

15 These press-formed compacts were used as the samples. The temperature at which an experimental sintered compact prepared by sintering in the temperature range of 800°C to 1,250°C is sufficiently dense is selected, and each sample was sintered at the corresponding selected temperature.

20 Sintering of the sample was conducted after the sample was heated in air at 500°C to 600°C to remove the binder. The sintering of the sample was conducted by heating the sample at the above-described selected temperature for 2 hours.

The resulting cylindrical sinters were each polished to 25 prepare a flat and smooth setter surface and then analyzed

by a dielectric resonator method (short-circuited at both ends of a dielectric resonator) to determine the relative dielectric constant ϵ_r and the Q value ($Q = 1/\tan\delta$). Since the dielectric loss varies depending on the measurement 5 resonant frequency f_0 , the dielectric loss was evaluated in terms of the fQ value, which is a product of f_0 and Q and is a constant value dependent on the material of the sample but independent from the frequency. The temperature characteristic τ_f of the resonance frequency was determined 10 from the rate of change in resonant frequency with varying temperature with reference to the resonant frequency f_0 at 25°C. The results of the measurement are shown in Tables 1 to 5.

Table 1

Sample No.	Composition of ceramic composition (molar ratio)					Sintering temperature (°C)	Characteristics of ceramic composition			Remarks	
	Ln ₂ O ₃ (Ln: Rare earth element)	B ₂ O ₃	RO (R: Alkaline earth metal element)	W _{O₃}	M ₂ O (M: Alkali metal element)		Filler (Al ₂ O ₃ or TiO ₂)	Relative dielectric constant ϵ_r	f _Q (GHz)		
1	La ₂ O ₃ *0.1000	*0.9000	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	800	9.1	7500	-41	13.5 Comparative Example
2	La ₂ O ₃ : 0.1500	0.8500	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	825	9.5	16500	-36	13.2 Invention Example
3	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	850	10.1	15600	-35	13.0 Invention Example
4	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	850	10.0	16000	-20	12.0 Invention Example
5	La ₂ O ₃ : 0.4000	0.6000	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	900	11.0	17500	-15	12.9 Invention Example
6	La ₂ O ₃ : 0.5000	0.5000	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	950	11.5	21000	-17	12.7 Invention Example
7	La ₂ O ₃ *0.6000	*0.4000	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	1200	11.8	10200	-25	12.4 Comparative Example
8	La ₂ O ₃ *0.6667	*0.3333	CaO: 0.0500	0.0100	0	Al ₂ O ₃ : 0.2000	1250	10.3	15000	-20	13.5 Comparative Example
9	La ₂ O ₃ : 0.2500	0.7500	*0	0.0100	0	Al ₂ O ₃ : 0.2000	1150	11.8	17000	-25	12.0 Comparative Example
10	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.0100	0.0100	0	Al ₂ O ₃ : 0.2000	1000	11.5	17500	-30	11.7 Invention Example
11	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.2000	950	11.7	17200	-37	11.2 Invention Example
12	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.2000	0.0100	0	Al ₂ O ₃ : 0.2000	900	11.4	16800	-42	11.4 Invention Example
13	La ₂ O ₃ : 0.2500	0.7500	CaO: *0.2500	0.0100	0	Al ₂ O ₃ : 0.2000	950	10.2	15800	-73	13.1 Comparative Example
14	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.2000	900	11.8	16800	-31	11.4 Invention Example
15	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.2000	900	10.0	17200	-31	12.7 Invention Example
16	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0300	0	Al ₂ O ₃ : 0.2000	850	10.2	18500	-35	12.4 Invention Example
17	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0500	0	Al ₂ O ₃ : 0.2000	850	10.1	17500	-39	12.8 Invention Example
18	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	*0.0700	0	Al ₂ O ₃ : 0.2000	850	9.8	7200	-59	13.1 Comparative Example
19	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	*0.1000	0	Al ₂ O ₃ : 0.2000	850	9.8	4300	-70	13.1 Comparative Example
20	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.1000	850	9.2	17400	-32	12.2 Invention Example
21	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.3000	900	9.1	18000	-37	13.0 Invention Example
22	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.4000	950	8.5	18100	-38	13.9 Invention Example
23	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.5500	1100	7.8	12000	-29	14.0 Comparative Example
24	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 0.6000	1150	7.1	9500	-13	14.1 Comparative Example
25	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	Al ₂ O ₃ : 1000	910	10.0	16500	-31	12.1 Invention Example

Asterisks indicate that the marked features are outside the scope of the present invention.

Table 2

Sample No.	Composition of ceramic composition (molar ratio)					Sintering temperature (°C)	Characteristics of ceramic composition			Remarks
	Ln ₂ O ₃ (Ln: Rare earth element)	B ₂ O ₃	RO (R: Alkaline earth metal element)	W _{O₃}	M ₂ O (M: Alkali metal element)		Filler (Al ₂ O ₃ or TiO ₂)	Relative dielectric constant ϵ_r	f _Q (GHz)	
26	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	TiO ₂ : 0.3000	915	12.1	17200	.25 Invention Example
27	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	TiO ₂ : 0.4000	950	14.1	15000	.20 Invention Example
28	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	0	TiO ₂ : *0.5000	1125	14.3	9300	.25 Comparative Example
29	Nd ₂ O ₃ : *0.1000	*0.9000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	850	9.3	7200	.36 Comparative Example
30	Nd ₂ O ₃ : 0.1500	0.8500	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	900	10.2	16800	.39 Comparative Example
31	Nd ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	925	10.8	17500	.30 Invention Example
32	Nd ₂ O ₃ : 0.3300	0.6700	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	925	11.0	16000	.25 Invention Example
33	Nd ₂ O ₃ : 0.4000	0.6000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	950	12.0	18000	.20 Invention Example
34	Nd ₂ O ₃ : 0.5000	0.5000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	950	11.8	17500	.15 Invention Example
35	Nd ₂ O ₃ : 0.5500	0.4500	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	950	11.5	15200	.14 Invention Example
36	Nd ₂ O ₃ : *0.6000	*0.4000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	1050	10.1	11300	.21 Comparative Example
37	La ₂ O ₃ : 0.1000	0.8000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	900	10.5	17500	.30 Invention Example
38	La ₂ O ₃ : 0.2000	0.6000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	950	11.8	18000	.18 Invention Example
39	La ₂ O ₃ : 0.3000	0.5000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	900	11.7	17000	.14 Invention Example
40	La ₂ O ₃ : 0.3000	0.5000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	900	11.8	18000	.13 Invention Example
41	La ₂ O ₃ : *0.3000	*0.4000	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	1025	9.8	6300	.21 Comparative Example
42	La ₂ O ₃ : 0.3333	0.6667	BaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	950	10.6	15600	.35 Invention Example
43	La ₂ O ₃ : 0.3333	0.6667	BaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	1000	11.0	15000	.45 Invention Example
44	La ₂ O ₃ : 0.3333	0.6667	BaO: *0.2500	0	0	Al ₂ O ₃ : 0.1500	950	11.5	16200	.71 Comparative Example
45	La ₂ O ₃ : 0.3333	0.6667	SrO: 0.0100	0	0	Al ₂ O ₃ : 0.1500	1000	9.9	15000	.38 Invention Example

Asterisks indicate that the marked features are outside the scope of the present invention.

Table 3

Sample No.	Composition of ceramic composition (molar ratio)					Sintering temperature (°C)	Characteristics of ceramic composition			Remarks
	Ln ₂ O ₃ (Ln: Rare earth element)	B ₂ O ₃	RO (R: Alkaline earth metal element)	WO ₃	M ₂ O (M: Alkali metal element)		Filler (Al ₂ O ₃ or TiO ₂)	Relative dielectric constant ϵ_r	fQ (GHz)	
46	La ₂ O ₃ : 0.33333	0.66667	SiO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	1000	10.2	15000	-35
47	La ₂ O ₃ : 0.33333	0.66667	SiO*: 0.2500	0	0	Al ₂ O ₃ : 0.1500	950	10.8	12500	-70
48	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.0500	0	0	Al ₂ O ₃ : 0.1500	980	11.0	15200	-45
49	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	980	11.5	15000	-38
50	La ₂ O ₃ : 0.33333	0.66667	BaO: 0.0500	0	0	Al ₂ O ₃ : 0.1500	950	10.2	15000	-35
51	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	0	Al ₂ O ₃ : 0.1500	980	11.5	15000	-40
52	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	900	11.7	14500	-38
53	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0	Li ₂ O: 0.0020	Al ₂ O ₃ : 0.1500	850	9.8	15500	-40
54	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0	Li ₂ O*: 0.0025	Al ₂ O ₃ : 0.1500	800	6.8	<2000	Immeasurable
55	La ₂ O ₃ : 0.2500	0.7500	BaO: 0.0100	0	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	900	12.0	15100	-35
56	La ₂ O ₃ : 0.33333	0.66667	SiO: 0.1000	0	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	11.0	15300	-39
57	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	Na ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	10.2	15000	-35
58	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	Na ₂ O: 0.0020	Al ₂ O ₃ : 0.1500	800	8.0	15100	-36
59	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	Na ₂ O*: 0.0025	Al ₂ O ₃ : 0.1500	800	5.0	<2000	Immeasurable
60	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	**800	8.5	16100	-38
61	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	Na ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	**825	8.8	15000	-40
62	La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0	K ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	**825	9.0	15500	-38

Asterisks indicate that the marked features are outside the scope of the present invention.

Double asterisks indicate that the filler was mixed after preparation of the glass frit, and the resulting mixture was then sintered.

Table 4

Sample No.	Composition of ceramic composition (molar ratio)					Characteristics of ceramic composition				Remarks
	Ln ₂ O ₃ (Ln: Rare earth element)	B ₂ O ₃	RO (R: Alkaline earth metal element)	WO ₃	M ₂ O (M: Alkali metal element)	Filler (Al ₂ O ₃ or TiO ₂)	Sintering temperature (°C)	Relative dielectric constant ε _r	f _Q (GHz)	
63	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0	Rb ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	8.7	15000	-35
64	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0	Cs ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	8.5	15000	-33
65	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	10.2	16000	-40
66	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0.0300	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	7.8	15500	-45
67	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0.0500	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	7.0	15000	-49
68	La ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	*0.0600	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	800	6.8	9500	-65
69	Nd ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0.0300	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	850	7.5	16000	-41
70	Nd ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	0.0500	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1500	800	6.8	15000	-48
71	Nd ₂ O ₃ : 0.3333	0.6667	CaO: 0.1000	*0.0600	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.2000	800	6.3	6300	-68
72	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1000	950	11.3	16800	-33
73	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	TiO ₂ : 0.1000	1000	13.1	17200	-35
74	La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.2000	TiO ₂ : 0.1000	1000	13.1	17200
75	Nd ₂ O ₃ : 0.2500	0.7500	CaO: 0.0500	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.2500	TiO ₂ : 0.2500	1150	13.8	16000
76	La ₂ O ₃ : 0.2000	0.6000	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1000	TiO ₂ : 0.1000	900	11.8	15800
77	La ₂ O ₃ : 0.1500	0.7000	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.3000	TiO ₂ : 0.1000	950	9.5	15000
78	La ₂ O ₃ : 0.2000	0.6667	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1000	Al ₂ O ₃ : 0.1000	900	10.0	15500
79	La ₂ O ₃ : 0.2333	0.6667	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1000	Al ₂ O ₃ : 0.1000	900	10.5	15000

Asterisks indicate that the marked features are outside the scope of the present invention.

Table 5

Sample No.	Composition of ceramic composition (molar ratio)					Sintering temperature (°C)	Characteristics of ceramic composition			Remarks
	Ln ₂ O ₃ (Ln: Rare earth element)	B ₂ O ₃	RO (R: Alkaline earth metal element)	WO ₃	M ₂ O (M: Alkali metal element)		Filler (Al ₂ O ₃ or TiO ₂)	Relative dielectric constant ϵ_r	f _Q (GHz)	
80 La ₂ O ₃ : 0.33333	0.66667	CaO: 0.0500 BaO: 0.0500	0.0100	Li ₂ O: 0.0010 Na ₂ O: 0.0010	Al ₂ O ₃ : 0.1000	850	8.5	17500	-38	14.0 Invention Example
81 La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000 SrO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.1000	850	10.3	16500	-35	12.5 Invention Example
82 La ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	Li ₂ O: 0.0020	Al ₂ O ₃ : 0.1000	850	10.2	16500	-36	12.5 Invention Example
83 La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.2000 TiO ₂ : 0.2000	1000	11.5	17000	-30	10.5 Invention Example
84 La ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ *: 0.3000 TiO ₂ *: 0.3000	1150	10.8	7400	-35	12.2 Comparative Example
85 Nd ₂ O ₃ : 0.2500	0.7500	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.3000	1000	11.0	15000	-33	11.8 Invention Example
86 Nd ₂ O ₃ : 0.33333	0.66667	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.40000	1000	11.2	16000	-38	11.2 Invention Example
87 Nd ₂ O ₃ : 0.50000	0.50000	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.30000	1000	11.1	15800	-35	11.8 Invention Example
88 Nd ₂ O ₃ : 0.50000	0.50000	CaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.30000	980	12.1	15000	-30	9.7 Invention Example
89 Nd ₂ O ₃ : 0.50000	0.50000	CaO: 0.1000 BaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.30000	950	11.8	16500	-40	11.5 Invention Example
90 Nd ₂ O ₃ : 0.50000	0.50000	CaO: 0.1000 BaO: 0.1000	0.0200	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.30000	950	10.5	16500	-41	12.0 Invention Example
91 La ₂ O ₃ : 0.2500 Nd ₂ O ₃ : 0.2500	0.50000	CaO: 0.1000 BaO: 0.1000	0.05000	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.30000	900	10.3	15000	-38	11.5 Invention Example
92 La ₂ O ₃ : 0.30000 Nd ₂ O ₃ : 0.2500	0.45000	CaO: 0.1000 BaO: 0.1000	0.0100	Li ₂ O: 0.0010	Al ₂ O ₃ : 0.30000	1000	10.4	15500	-40	10.3 Invention Example

Asterisks indicate that the marked features are outside the scope of the present invention.

The results shown in Table 1 to 5 show that nearly all of the invention examples exhibited an fQ value of 15,000 GHz or more, a low dielectric loss in the high-frequency band, and a resonant frequency temperature coefficient τ_f of 5 within ± 50 °C/ppm. This is presumably due to the effect of incorporating Ln_2O_3 into the glass composition together with the filler. At a small Ln_2O_3 content, the fQ value is low, as shown by Samples 1 in Table 1 and Sample 29 in Table 2.

The invention examples produced sufficiently dense 10 sinters having high fQ values even at a sintering temperature of 1,000°C or less. This is because the contents of the Ln_2O_3 , RO, Al_2O_3 , and TiO_2 are limited within particular ranges. This fact is clearly supported by the results of Samples 7, 8, 9, 23, 24, 28, 36, 41, 47, 74, and 15 84 compositions which were outside the ranges of the invention, since they did not achieve the target fQ value or they required high sintering temperatures.

RO has an effect of decreasing the sintering 20 temperature. However, at an excessively large RO content, the temperature coefficient τ_f of the resonant frequency tends to be excessively shifted toward the negative side, as shown by Samples 13, 44, and 47.

Incorporation of WO_3 or M_2O decreases the sintering 25 temperature, and WO_3 or M_2O can be effectively used by controlling its content. At an excessively large content,

however, a significant decrease in f_Q value or degradation of temperature coefficient τ_f may result, as shown by Samples 18, 19, 54, 59, 68, and 71.

5 Industrial Applicability

A ceramic composition of the present invention has a low dielectric loss in the high-frequency band and low temperature dependence of the resonant frequency. Moreover, since its characteristics can be exhibited at a low sintering temperature, a metal, such as Ag or Cu, having a low specific resistance can be used as the material for the metal wiring or electrode, and the conductor loss can thus be decreased. The ceramic composition of the present invention is thus suitable for the substrate materials for high-frequency band multilayer substrates and the materials for electronic components.